Development and performance of the PIPER scalable child Human Body Models

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Motivation

- Children restrain conditions are more diverse than adult's

- Assessment relies on dummies

- Finite Element Human body models (HBM) have potential to be:

  - more robust than dummies to diversity of loading conditions (describe anatomy…), omnidirectionality

  - Scaled, positioned,

  - Could be used to study injury (reco)

- However: child HBM less available and advanced than adult's

  - Challenges: validation data, growth…
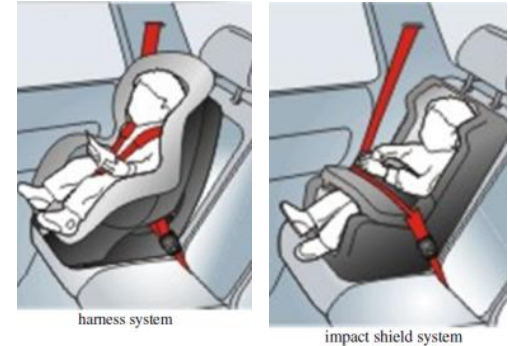

*Johannsen Pocc 2013*
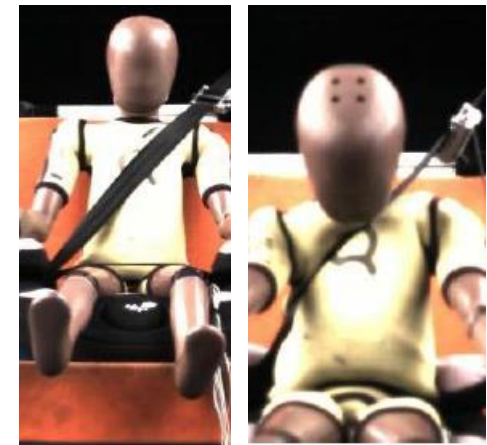
Beillas Ircobi 2014

Status and objectives

- Last year: ongoing dev. Efforts in PIPER EU project
    - Based on LBMC models (Beillas et al., 2013)
    - Body region models (head, neck, shoulder)
    - Not assembled, limited validation
    - Scaling methodology
- Aims of this study: Report
    - Finalization of model development
    - Scaling/positioning: integration PIPER tool
    - Validation status
    - Perspectives and upcoming availability

3 YO   6 YO

PoCC 2015
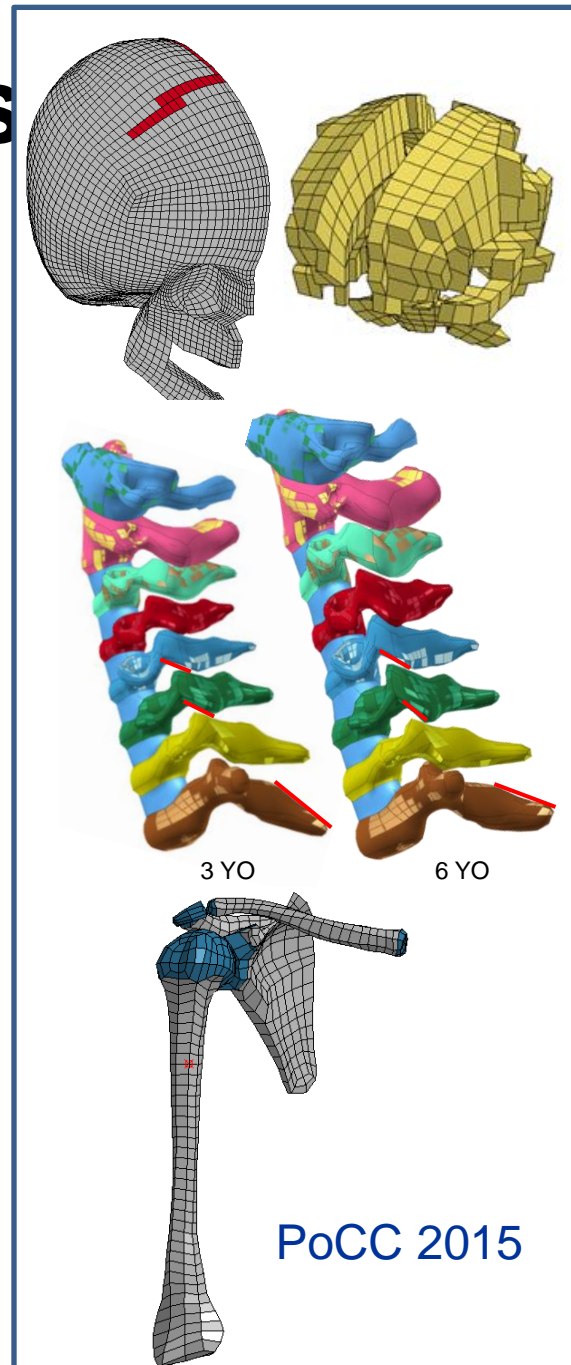
Methods: model overview

- Main development phase completed
  - Multiple iterations, model almost fully remeshed
- Baseline: 6YO with anthro. normalized based on GEBOD regressions
  - 6YO, stature: 1146 mm
  - 15 dimensions used: seated height: 631 mm, …
- Model summary:
  - 353 parts, ~531,000 elements (52,000 rigid)
  - 23kg, Time step: 0.32µs (15 grams mass scaling), Ls-Dyna3D
- Geometry: bone and organs
  - Multiple CT scans (1.5, 3, 6 YO) for cartilage +anatomical descriptions + foot from adult scan (rigid)
  - Scaling / assembled at 6 YO
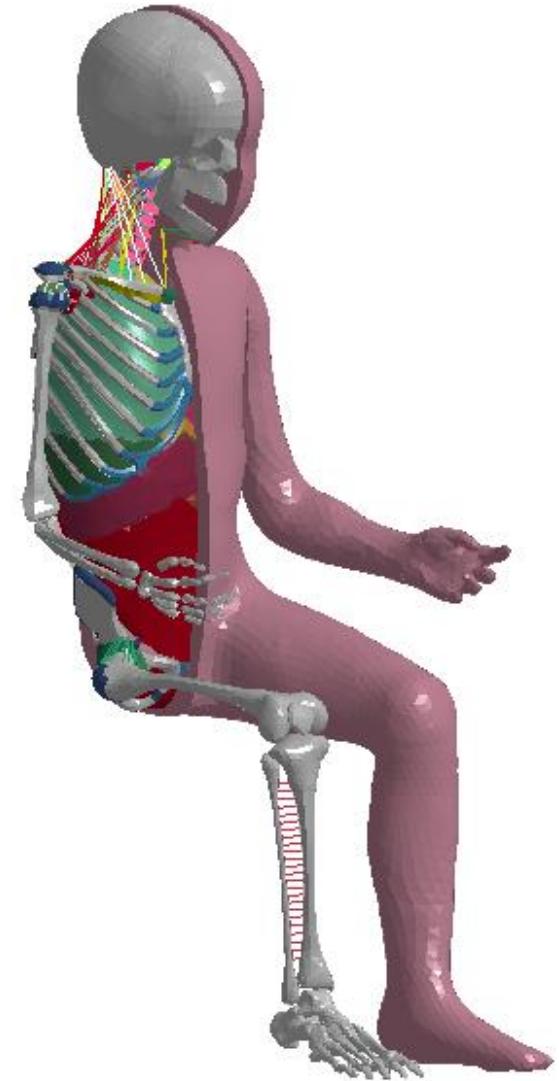
Methods: model overview

- Postural adjustment:
    - Spine: based on upright MRI (Beillas et al., 2009)
    - Shoulder & extremities: manual…
- Skin: Assembly from CT + deformation based on skeleton + by UMTRI body shape data
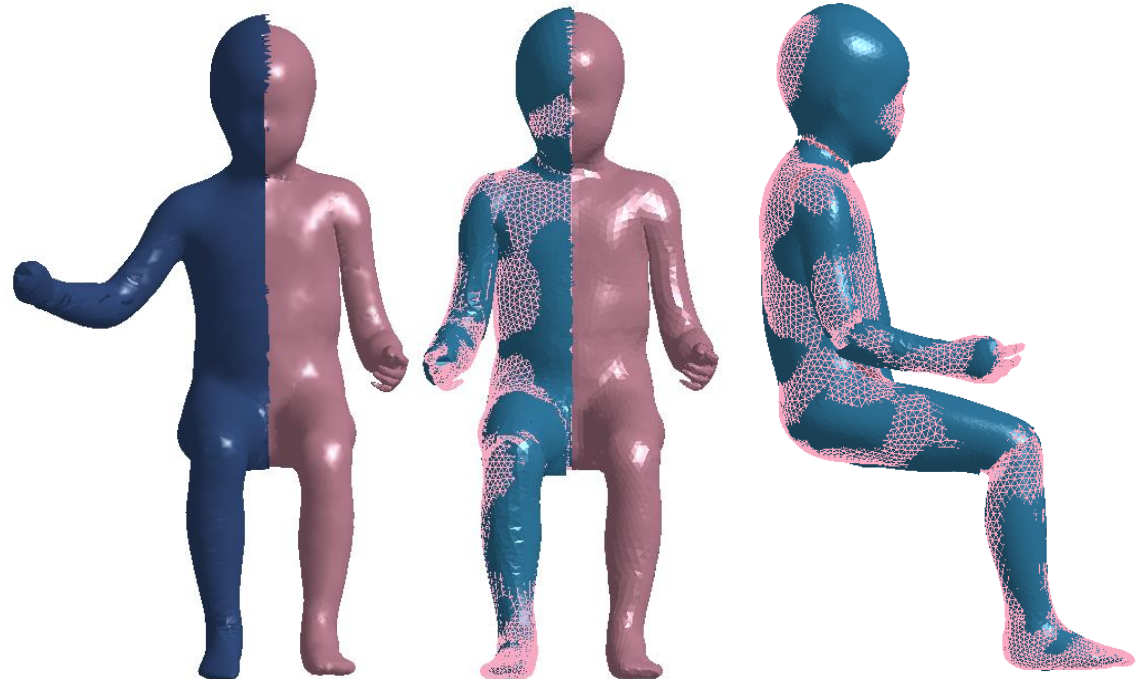- Verification:
    - Blue: UMTRI
    - Pink: PIPER model

➔ Shape is very close
➔ Plausible

UMTRI statistical shape model
http://childshape.org

Parameters

STATURE		1146
BMI		17.05
SHS		0.55
Recline		11
Flex		50

Methods: regional descriptions

- Head model (Giordano and Kleiven, Ircobi 2016 +brain remeshed):

  - Deformable skull, brain, meninges, brain stem, …
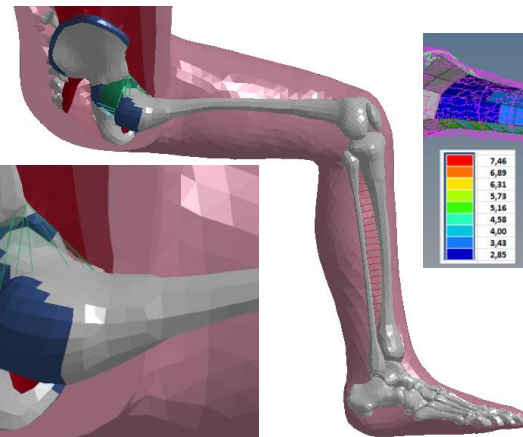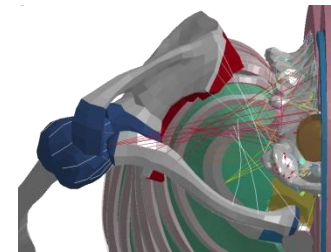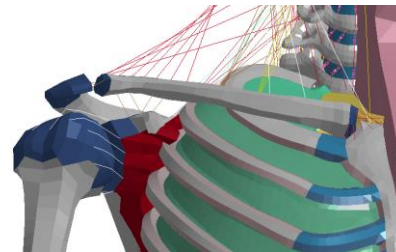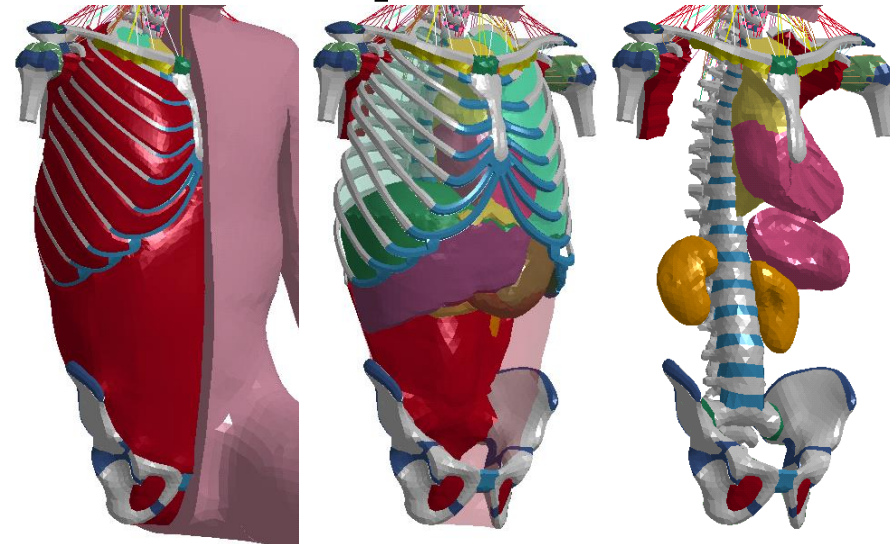 - ~44k elements (3 to 5 mm)
  - Properties: literature

- Neck model (from last year)

  - Mesh updated (quality)
  - Fully deformable, muscles added (1D)
  - ~25k elements
  - Properties: literature
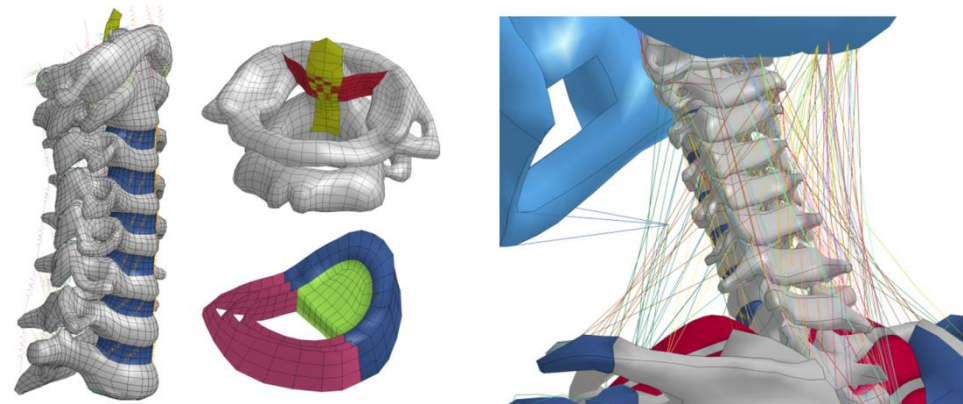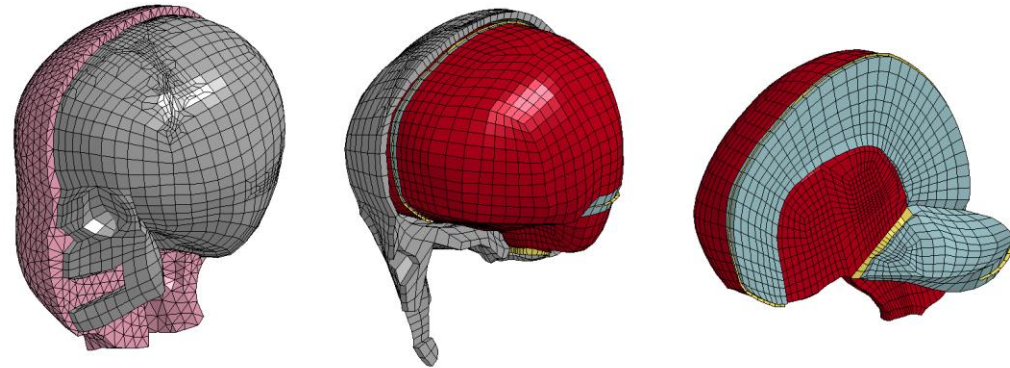
Methods: regional descriptions

- Trunk (thorax, abdo, pelvis)
  - Deformable pelvis (new) & ribcage, remeshed spine (still rigid, 6 d.o.f. beams)
  - Soft organs: added abdo muscles, pancreas, better shapes+gaps (liver, heart, diaphram)
- Extremities
  - Shoulder & hip: deformable bones & cartilage, capsule and ligaments, contacts
  - Epiphyses at knee, elbow, wrist +hand, foot: forearm: rigid bodies +6 d.o.f. beams
  - Other diaphyses: deformable

Results: integration in PIPER tool

- PIPER tool metadata
- Scaling
  - External anthro + local points neck and head integrated
  - 18-72 MO (could be height)

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Few distorted elements
Work on fix ongoing

Runnability of scaled models

Criteria	Selected	Min or Max		(%)
		6yo ➜ 3yo	2yo	
Jacobian	> 0.3	0.23 - 0.22	-0.14	<5e-4
Warpage	< 50°	94 - 103°	179	
Min Quad Ang.	> 15°	15	13.4	
Max Quad Ang.	< 165°	165-164	343	
Aspect Ratio	< 8	13.3 -13.7	14.1	1e-3
Min Length	> 1 mm	0.33 ➜ 0.21	0.15	5-6

10mm nugget ➜ Fixed

Results: integration in PIPER tool

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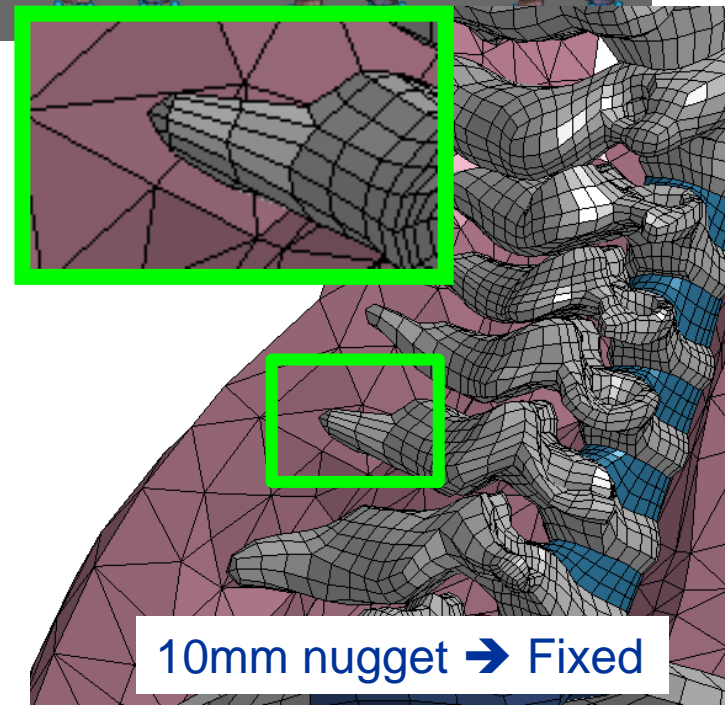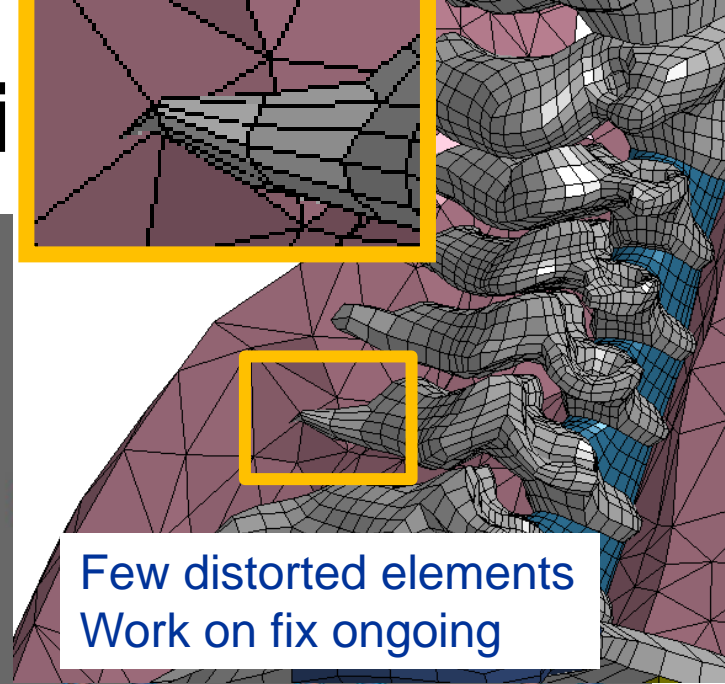 - 18-72 MO (could be height)

➜ Corrected manually: Runnable models

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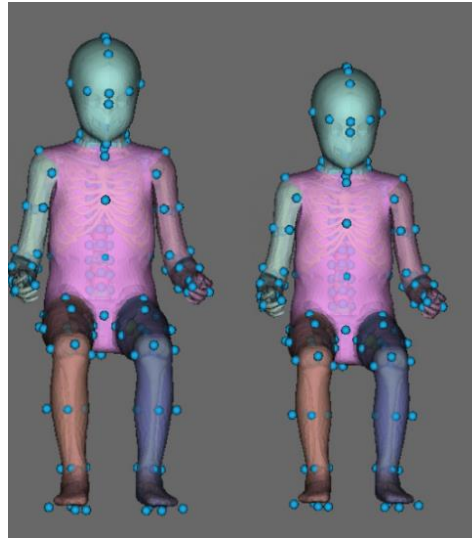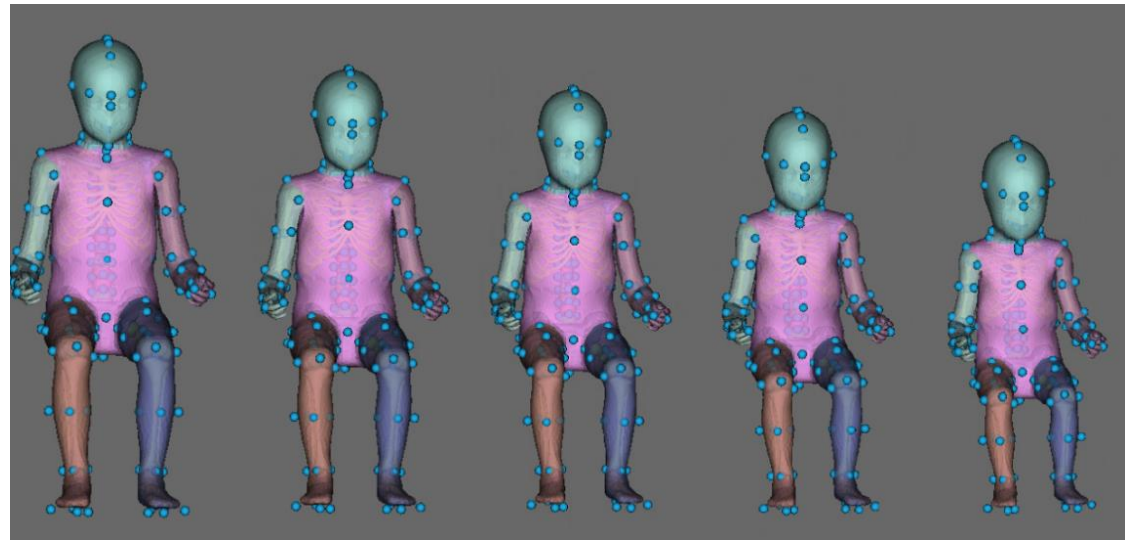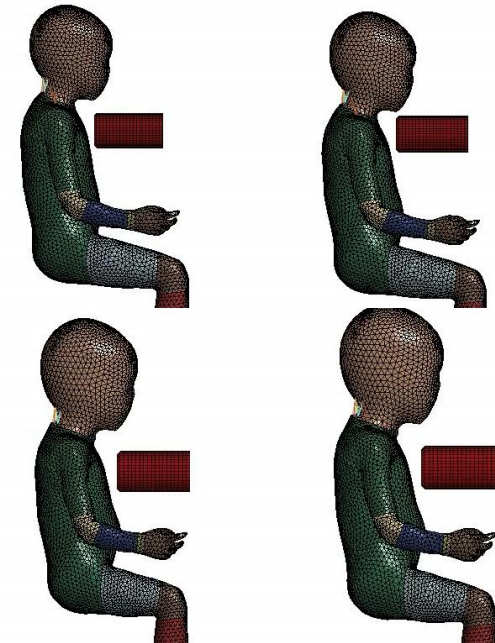   - 18-72 MO (could be height)

- Positioning
    - Pre-positioning: realtime simulation
    - → Target defined
    - Transformation:
        - Direct + smoothing
        - By simulation (bone = target; ongoing)
        - By contour
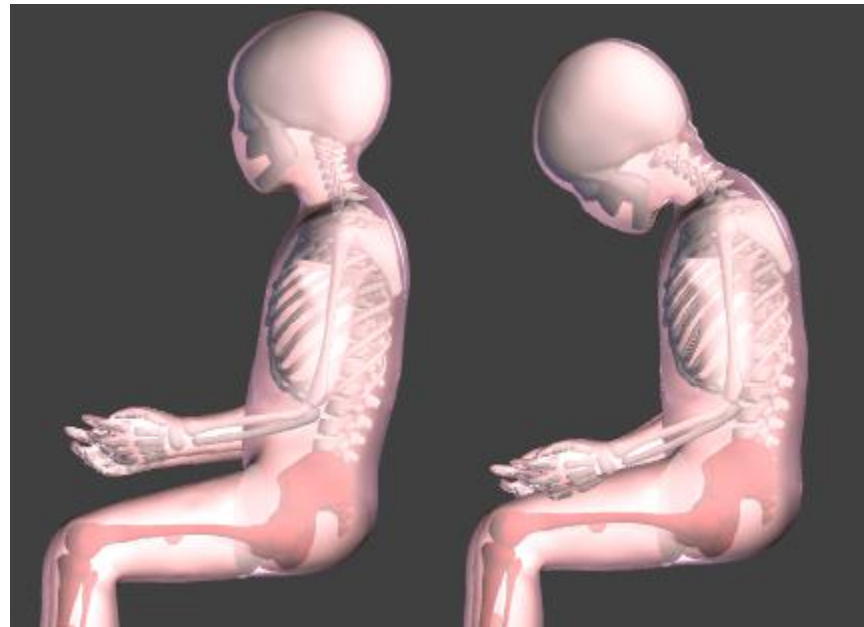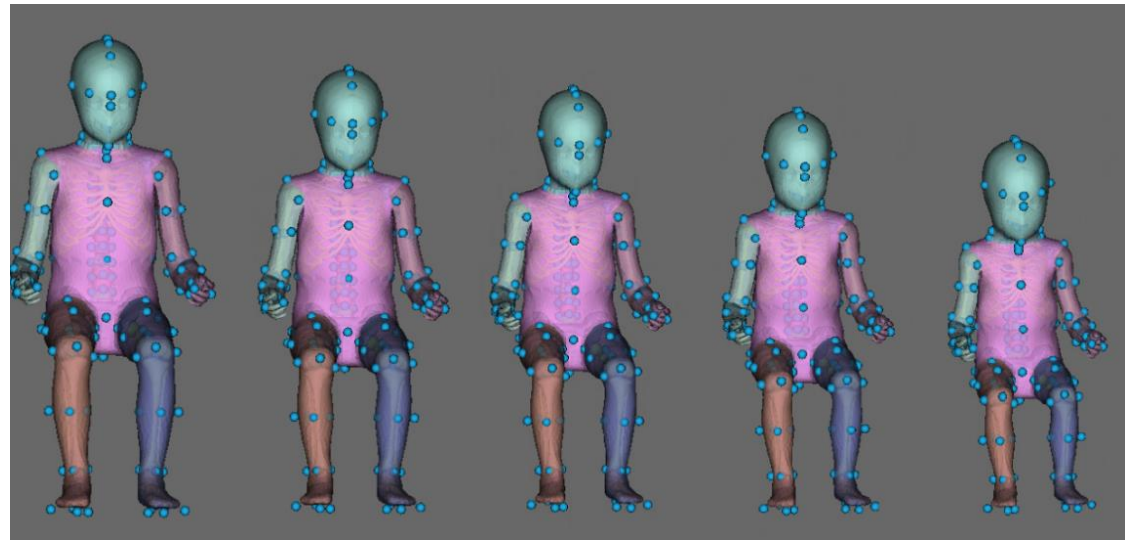
Results: validation

- Quite large candidate validation matrix. Not everything run yet, not exactly the same version of model… 3 sets

1) Most regions, main loading…

2) Planned (ages)

3) Unsure: Redundant ? Needed? Data?

Set	Published Study	ROI	Dir	Impactor/loading	Subjects and ages		Target model and version	
1	Loyd (2011)	Head		Drop test (dyn)	PMHS	9	6	0.3
	Loyd (2011)	Head		Compression (dyn)	PMHS	9	6	0.3
	Ouyang et al. (2005)	Neck		Bending+tensile	PMHS	6	6	0.3
	Ouyang et al. (2005)	Neck		Bending+tensile	PMHS	3	3	0.3
	EEVC Q (2008)	Shoulder	Side	Pendulum, free back (dyn) Scaled	PMHS	Adult	6	0.202
	Ouyang et al (2006)	Thorax	Frontal	Pendulum, free back (dyn)	PMHS	6+	6	0.202
	Kent et al (2011)	Thorax	Frontal	Belt distributed, fixed back (dyn)	PMHS	6 & 7	6	0.202
	Kent et al (2011)	Thorax	Frontal	Belt diagonal, fixed back (dyn)	PMHS	6 & 7	6	0.202
	EEVC Q (2008)	Abdo	Frontal	Belt, fixed back Scaled corr.	Porcine	6	6	0.202
	Kent et al (2011)	Abdo	Frontal	Belt mid abdo, fixed back (dyn)	PMHS	6 & 7	6	0.202
	Kent et al (2011)	Abdo	Frontal	Belt upper abdo, fixed back	PMHS	6 & 7	6	0.202
	Part 572	Lumbar	Frontal	Torso flexion (static)	HIII	6	6	0.202
	Ouyang et al (2003a)	Pelvis	Side	Pendulum, free back (dyn)	PMHS	various	6	0.202
	Ouyang et al. (2003b)	Femur		Bending test	PMHS			0.301
	Wismans et al (1979)	WB neck	Frontal	Sled test, harness (4 YO anthro)	PMHS	6	6	0.3
	Kallieris et al (1976)	WB	Frontal	Sled test with shield	PMHS	2.5, 6		*
	Lopez et al (2011)	WB spine	Frontal	Sled test with belt (dyn)	Volunteer		6	*
	Arbogast et al (2009)	WB neck	Frontal	Sled test, 3pt belt	Volunteer	6+	6	*

*= with a previous version of the model. Need to be updated.

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	EEVC Q (2008)	Shoulder	Side	Pendulum, free back (dyn) Scaled	PMHS	Adult	3	*
	EEVC Q (2008)	Shoulder	Side	Pendulum, free back (dyn) Scaled	PMHS	Adult	1.5	planned
	Loyd (2011)	Head		Drop test (dyn)	PMHS	1.5	1.5	0.202
	Loyd (2011)	Head		Drop test (dyn)	PMHS	1	1	0.202
	Loyd (2011)	Head		Compression (dyn)	PMHS	1	1	0.202
2	Luck et al. (2008)	Neck		Tensile	PMHS	1.5	1.5	planned
	Luck et al. (2012)	Neck		Tensile segments	PMHS	1.5, 6	1.5, 6	planned
	Luck et al. (2012)	Neck		Bending segments	PMHS	1.5, 6	1.5, 6	planned
	Ouyang et al (2006)	Thorax	Frontal	Pendulum, free back (dyn)	PMHS	2-5	1.5	*
	Ouyang et al (2006)	Thorax	Frontal	Pendulum, free back (dyn)	PMHS	2-5	3	*
	Chamouard (1996)	Thigh	Vertical	Belt compression (static)	Volunteer		6	*

*= with a previous version of the model. Need to be updated.

Results: validation

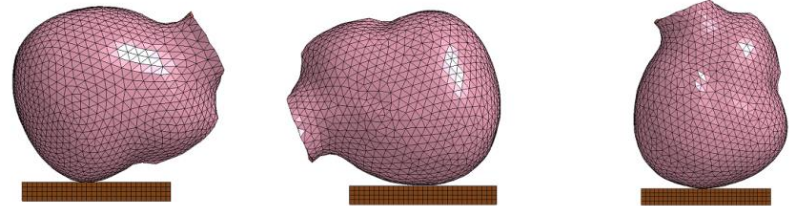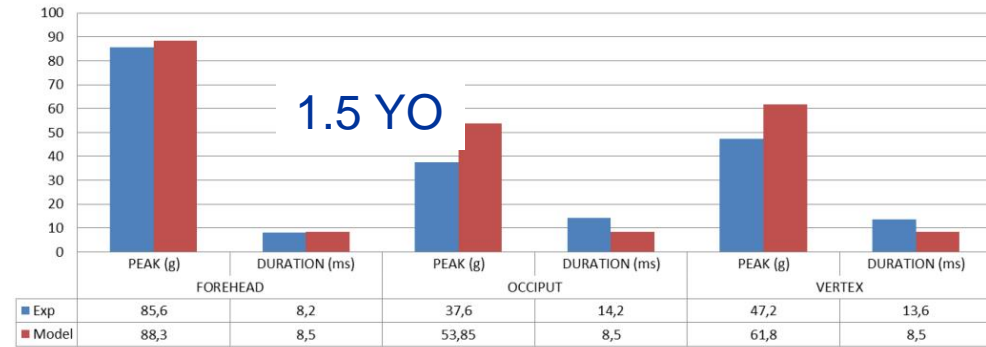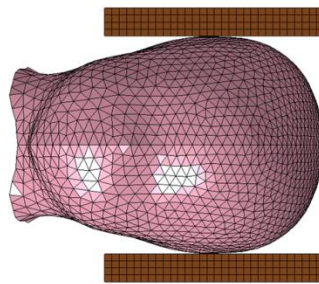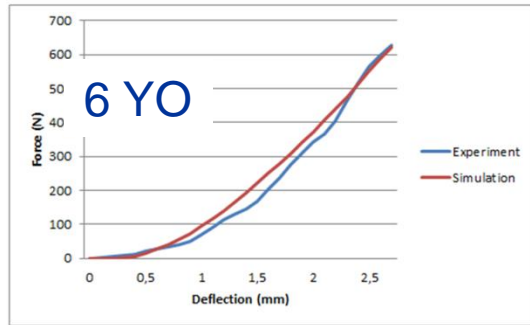- Quite large candidate validation matrix. Not everything run yet, not exactly the same version of model… 3 sets

1) Most regions, main loading…

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	Davidson et al (2013)	Shoulder	Frontal	Arm pull, shoulder mobility	Volunteer	Adult		planned
	Kent et al (2011)	Abdo	Frontal	Belt lower abdo (dyn)	PMHS	6 & 7	6	*
	EEVC Q (2008)	Abdo	Frontal	Belt, fixed back Scaled corr.	Porcine	1.5	1.5	
	EEVC Q (2008)	Abdo	Frontal	Belt, fixed back Scaled corr.	Porcine	3	3	
	Kent et al (2008)	Abdo	Frontal	Belt, fixed back (dyn)	Porcine	6	6	*
3	Ouyang et al (2006)	Abdo	Frontal	Pendulum, free back (dyn)	PMHS	2-5	1.5	
	Ouyang et al (2006)	Abdo	Frontal	Pendulum, free back (dyn)	PMHS	2-5	3	
	Ouyang et al (2006)	Abdo	Frontal	Pendulum, free back (dyn)	PMHS	6-?	6	
	Chamouard (1996)	Abdo	Frontal	Belt compression (static)	Volunteer		6	*
	Seacrist (2014)	WB	Oblique	Sled test (dyn)	Volunteer	6-8	6	
	Ita et al (2014)	WB	Lateral	Shoulder test	Volunteer	4-7	6	

*= with a previous version of the model. Need to be updated.
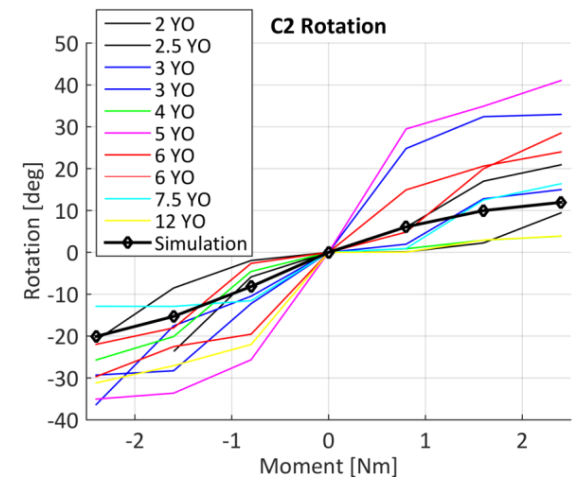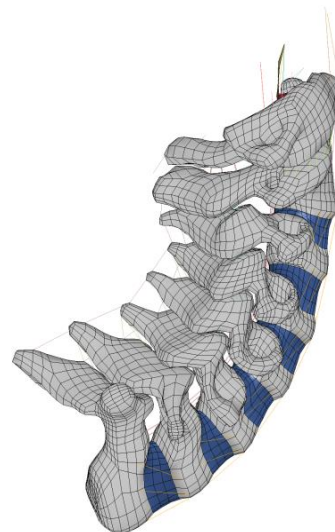
Results: validation examples

- Head: Matching well overall

6 YO

1.5 YO

| | FOREHEAD | | OCCIPUT | | VERTEX | |
	PEAK (g)	DURATION (ms)	PEAK (g)	DURATION (ms)	PEAK (g)	DURATION (ms)
Exp	85,6	8,2	37,6	14,2	47,2	13,6
Model	88,3	8,5	53,85	8,5	61,8	8,5

Loyd (2011) (PMHS)

- Neck: within experimental range

Ouyang et al. (2005) (PMHS)

C2 Rotation

Results: validation examples
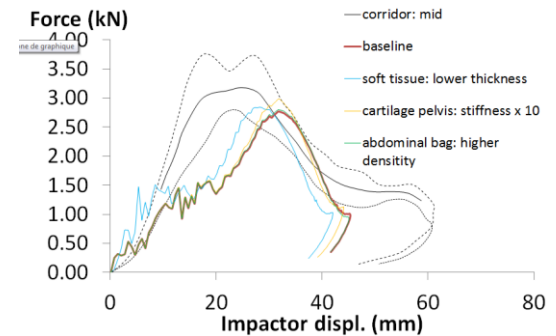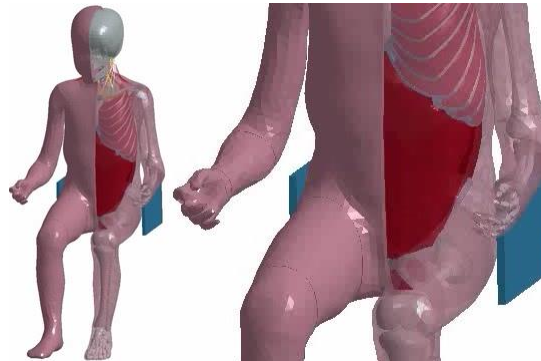

- Trunk:
  - frontal ok
  - Side: some differences
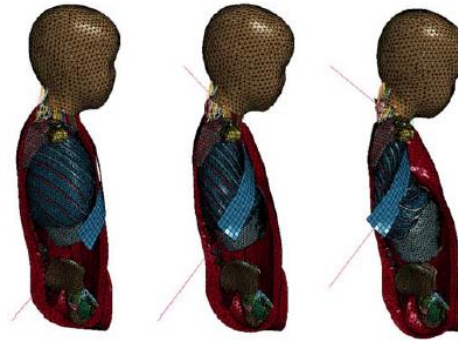
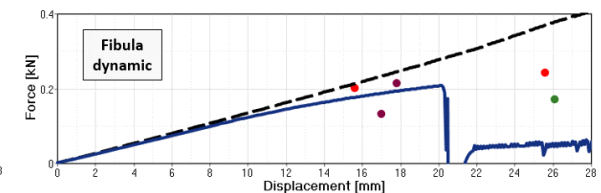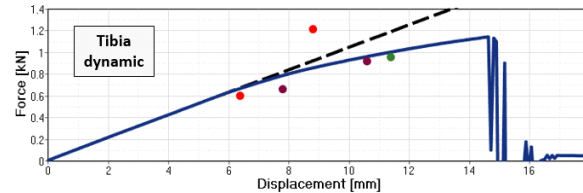Kent et al. (2011) (PMHS)
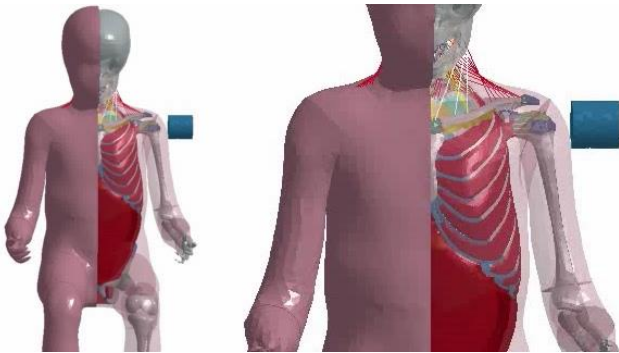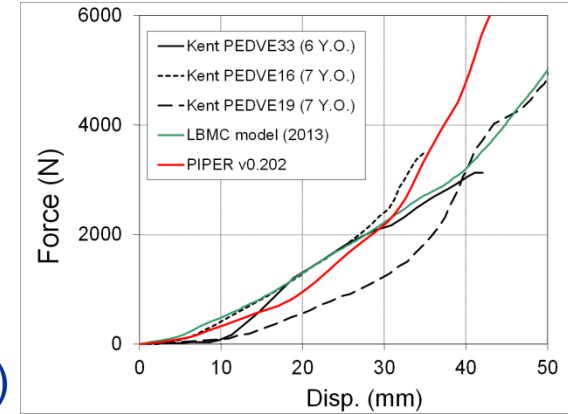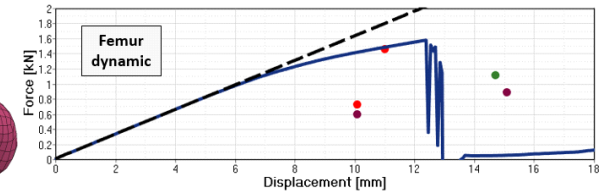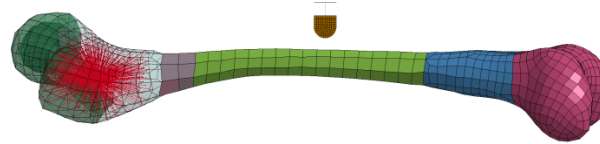

Irwin et al. (2003) Scaled
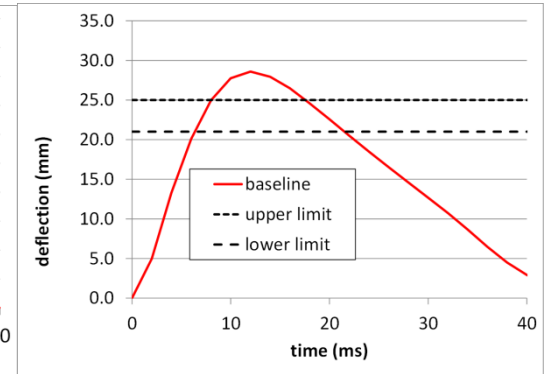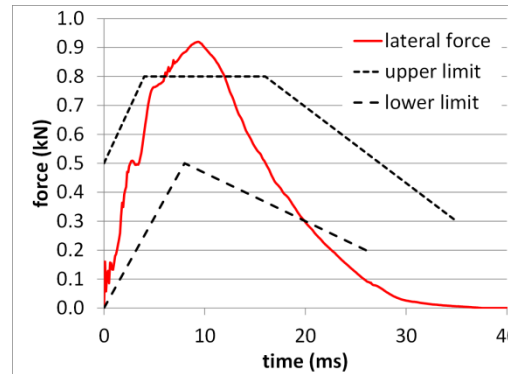
Ouyang side (PMHS)

Results: validation examples

- ## Lower ext diaphyses: ok

  Ouyang et al (2003) PMHS

- ## Whole body repetition with all updated components ongoing (expected ok)


Wismans et al. (1979)

Discussion and conclusions

- Mesh complete ➜ preparing for release
- Repetition of all validation cases ongoing
    - Results encouraging ➜ seems to capture most known responses. Some mismatch ➜ sensitivity analyses ongoing to try understand causes
        - erroneous modelling assumption,
        - Incompatibility between setups (need more 1 model)
        - Data scaling assumptions
- Scaling: works fine for anthropometry
    - Mostly external ➜ refine a bit?
    - PIPER tool: need to integrate material, joints, thickness scaling

Discussion and conclusions

- Applications in the short term:
  - Scale model using arbitrary anthro predictors
    - Snyder et al (1977) DB + Parkinson Reed method
  - ➔e.g. R129 dimensions constraint
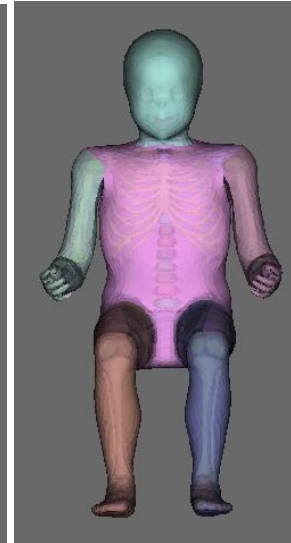 - ➔ Scale to other anthropometry (e.g. chinese)
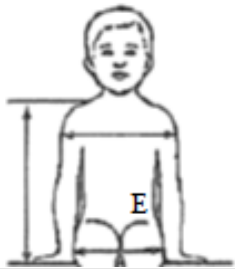
Stature cm	Minimum Sitting height cm	Minimum Shoulder breadth
A	B	C
	95%ile	95%ile
...		
110	63.9	30.9
115	66.0	32.1

Prelim: Suject with widest shoulder width In Snyder (close 95th R129)

Collab. Tongji Univ.: Chinese anthro (older model)

Discussion and conclusions

- Applications / capability in the short term:
    - Scale model using arbitrary anthro predictors
        - Snyder et al (1977) DB + Parkinson Reed method
    - ➔e.g. R129 dimensions constraint
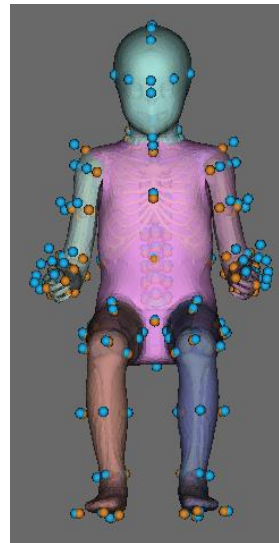   - ➔ Scale to other anthropometry (e.g. chinese)
    - Positioning (submarining, UMTRI)
    - Some accident reconstructions (CASPER…)
- Beyond PIPER: work on tolerance level
    - Reconstructions?

Discussion and conclusions

- Availability: public release April 30, 2017 at latest
    - **Final Workshop: Paris, April 24 or 25** (save the dates)
    - PIPER Child model with all validation setups, PIPER tools
    - Beta testing…
- Release license: aims: free/open; we can all use them, make them better but they have to remain free/open for all

➔ **Licence Open Source GPL** (=modifications allowed, distribution require making changes available, cannot prevent redistribution, compatible service model, usable commercial, academic…)

    - PIPER Model: GPLv3 +Open science clause: model must be made available if used in publication (➔reproducibility)
    - PIPER Tools: GPLv2 or later

Thank you

Final Workshop in Paris
24-25 April 2017 (save date)

http://www.piper-project.eu/
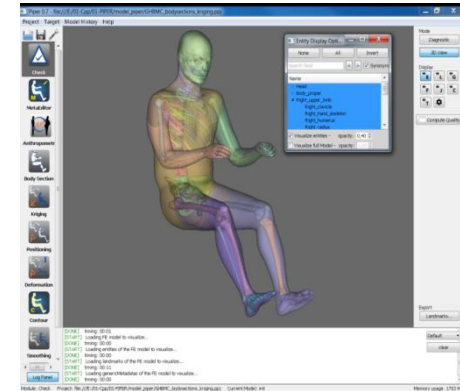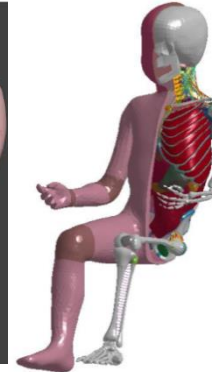
PIPER Contributors, P. Petit (LAB Peugeot Renault) P. Beillas, X. Wang, Y. Lafon, M.C. Chevalier, T. Janak, M. Mear, T. Dupeux, J. Collot (Univ. Lyon 1-Ifsttar), S. Kirscht (TU Berlin), S. Kleiven, C. Giordano, V. Alvarez, X. Li (KTH), Chawla, A. Chhabra S. Paruchuri S. Singh (FITT, IN), E. Jolivet (CEESAR, FR), F. Faure, B. Gilles, T. Lemaire (INRIA) N. Praxl, J. Peres (PDB), A. Bhaskar, C. Lecomte (SOTON)